On the determination of α_S from jet rates in deep inelastic scattering at HERA

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Differential jet rate analysis

y_2 averaged over range of $Q^2 > 200$ GeV^2

Integrated 2+1 jet rate analysis

R_{2+1} as a function of Q^2 for fixed y_{cut}

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Cluster algorithms

JADE like algorithms

- add missing momentum pseudo cluster (proton remant):
  remove scattered electron cluster
- look for pair of objects i, j with smallest inv. mass m_{ij}
  different definitions of m_{ij} are possible
- recombine i and j to a single jet
  different recombination schemes are possible
- iterate

Factorizable k_t algorithm

(as used later for the 2+1 jet rate)

- boost clusters to Breit frame:
  remove scattered electron cluster
- for each cluster i, d_{ip} and d_{ij} are calculated
  d_{ip}: distance to proton $(d_{ip} = 2E_i^2(1 - \cos\theta_{ip})/Q^2)$
  d_{ij}: distance to clusters j $(d_{ij} = 2\min(E_i^2, E_j^2)(1 - \cos\theta_{ij})/Q^2)$
- comparing d_{ip} and d_{ij}, cluster i is either assigned to a 're-
  mant' jet, or i and j are recombined if $d_{ij} < 0.5$

Definition of jet rates

Integrated jet rate

- clustering ends when no pair i, j with $m_{ij}^2/W^2 < y_{cut}$ is left
  (W is the total hadronic mass)

  all jets are considered to be resolvable
- from the number of $2+1$ jet events, the integrated jet rate $R_2(Q^2) \equiv \dfrac{N_{2+1}(Q^2)}{N_{tot}(Q^2)}$ is determined

Differential jet rate

- clustering is stopped when 2+1 jets are left
- for all events $y_2 \equiv \min m_{ij}/W^2$ is calculated
  (later a cut of $y_2 > 0.01$ is applied)

Outline

Differential jet rate

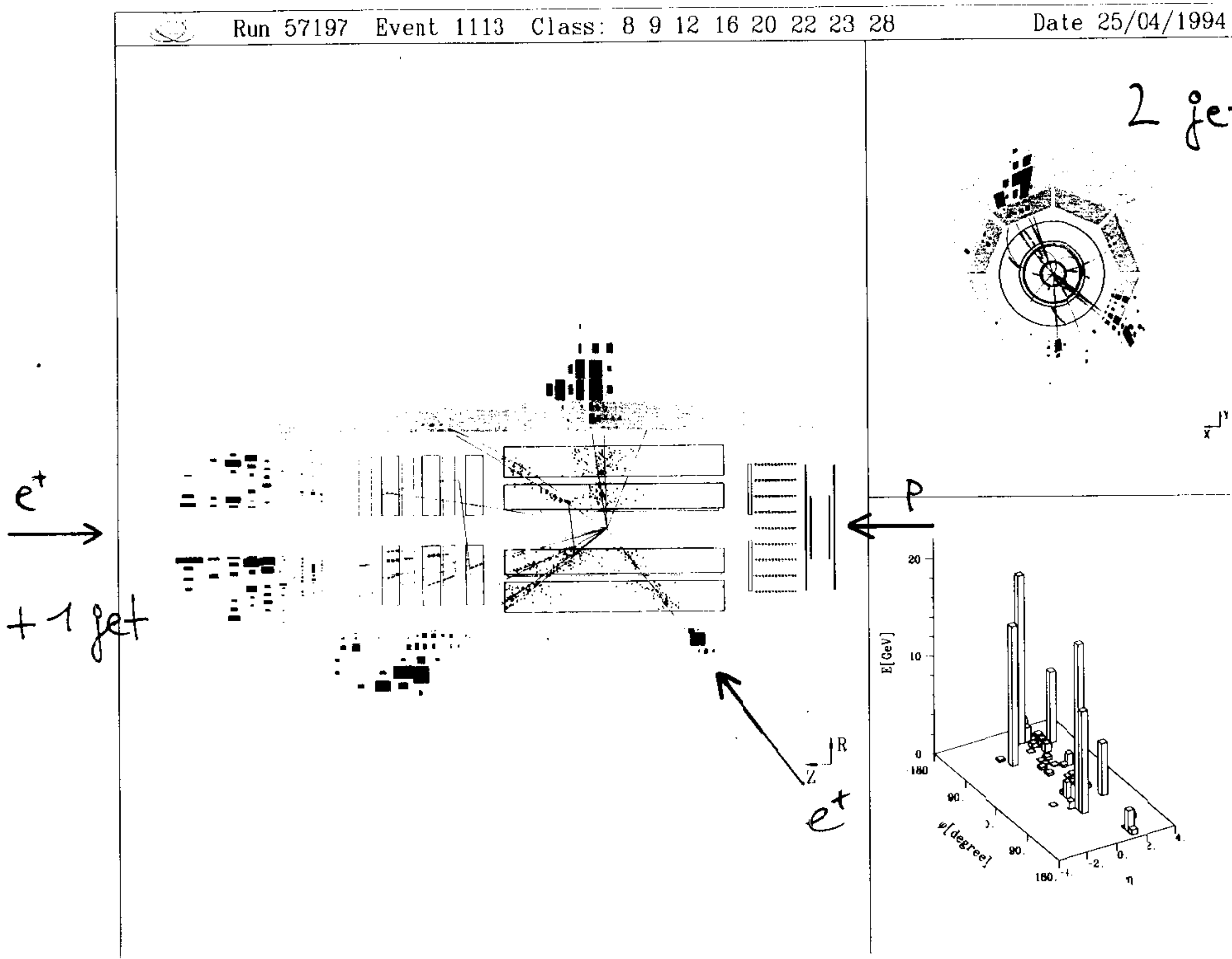
- description of data by QCD Monte Carlo models
  (ARIADNE 4.08, LEPTO 6.5)
- where does NLO describe the data?

  comparisons of partons from parton shower/dipole
  QCD Monte Carlos to exact NLO predictions
- unfolding of the differential jet rate
- fit of NLO predictions to unfolded jet rate
- quantitative estimate of systematic error

  acceptance cuts for detector clusters and partons
  renormalization scale dependence
  recombination scheme dependence

Integrated jet rate

- description of $R_{2+1}(Q^2)$ by QCD models
  (JADE jet algorithm)


Run 57197 Event 1113 Class: 8 9 12 16 20 22 23 28
Date 25/04/1994
2 jets
e^+
+ 1 jet
P
e^+
E[GeV]
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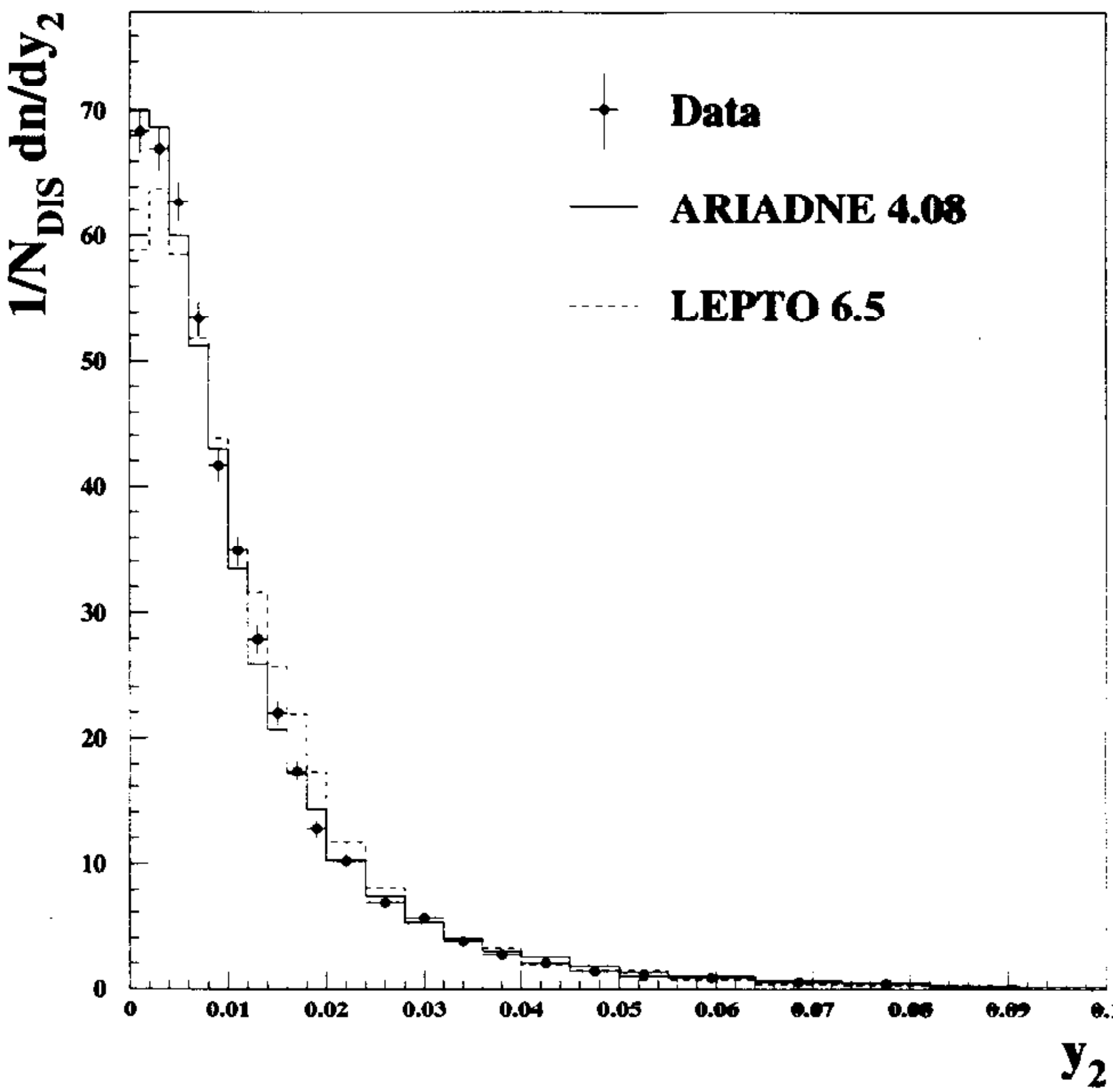
η

Comparison of Data vs Monte Carlo

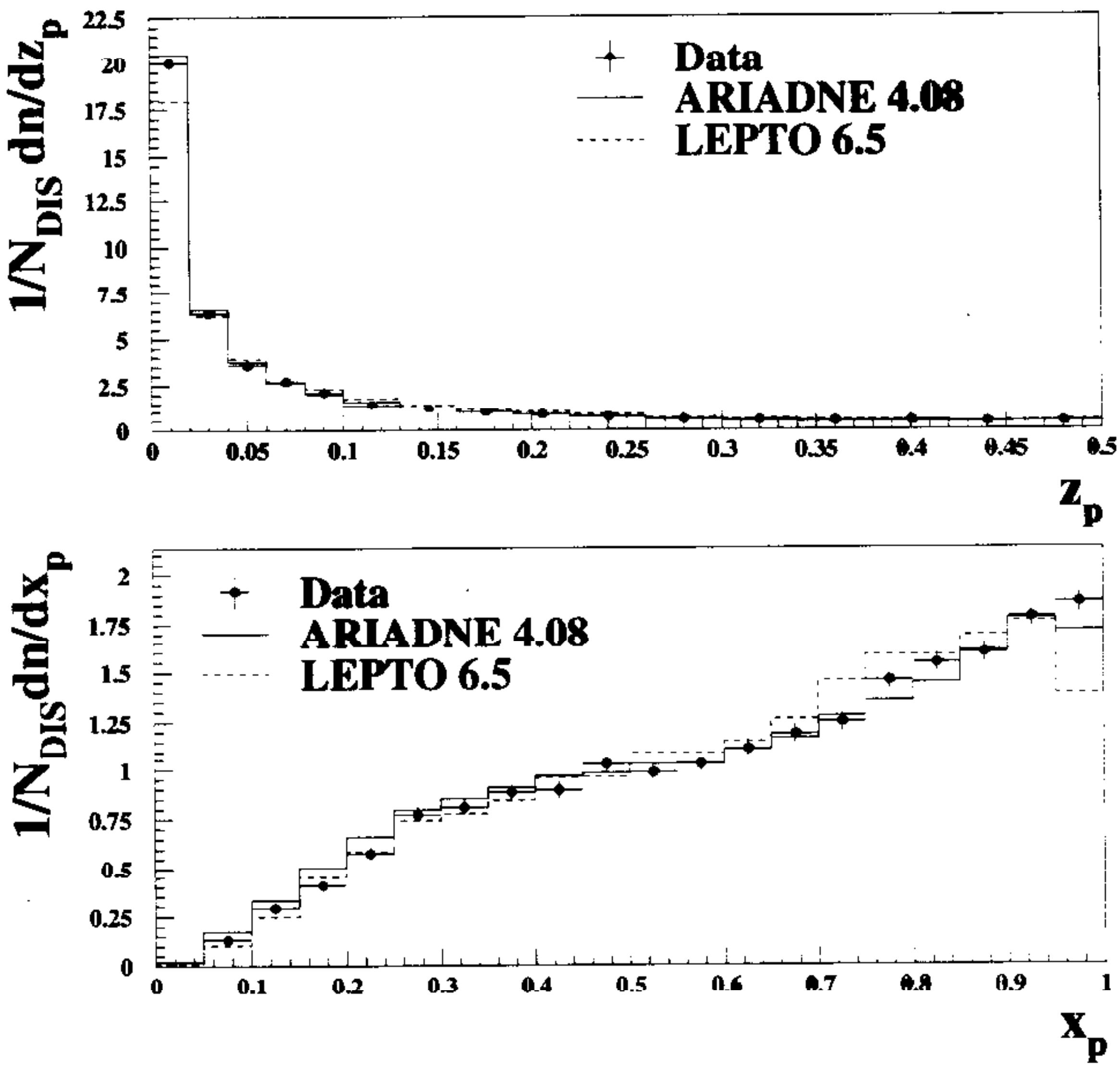
($Q^2 > 200$ GeV^2, $W^2 > 5\,000$ GeV^2, $y_2 > 0.01$, $\theta_{clus} > 7°$)



- excellent description of data by ARIADNE 4.08
  (parameters tuned to HERA data)
- poorer description by LEPTO 6.5

Comparison of Data vs Monte Carlo

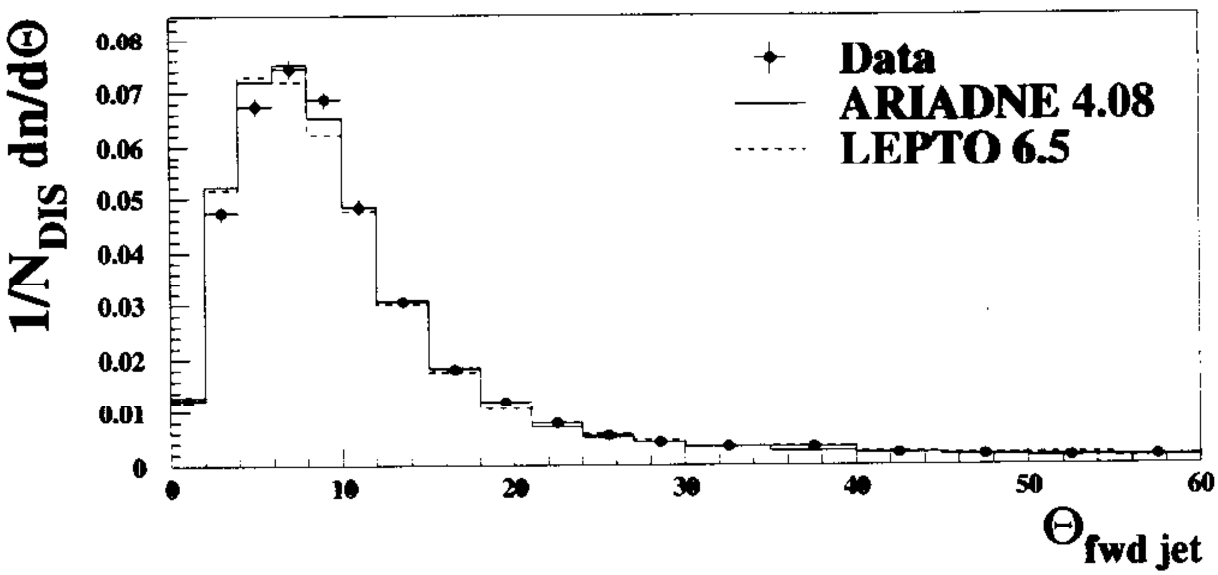
$(Q^2 > 200\ \mathrm{GeV}^2,\ W^2 > 5000\ \mathrm{GeV}^2,\ y_2 > 0.01,\ \theta_{clus} > 7^\circ)$



$$z_p = \frac{\min\limits_{i=1,2}\left(E_i\,(1-\cos\theta_i) \right)}{\sum\limits_{i=1,2} E_i\,(1-\cos\theta_i)}, \quad x_p = \frac{Q^2}{Q^2 + m_{12}^2}$$

Comparison of Data vs Monte Carlo

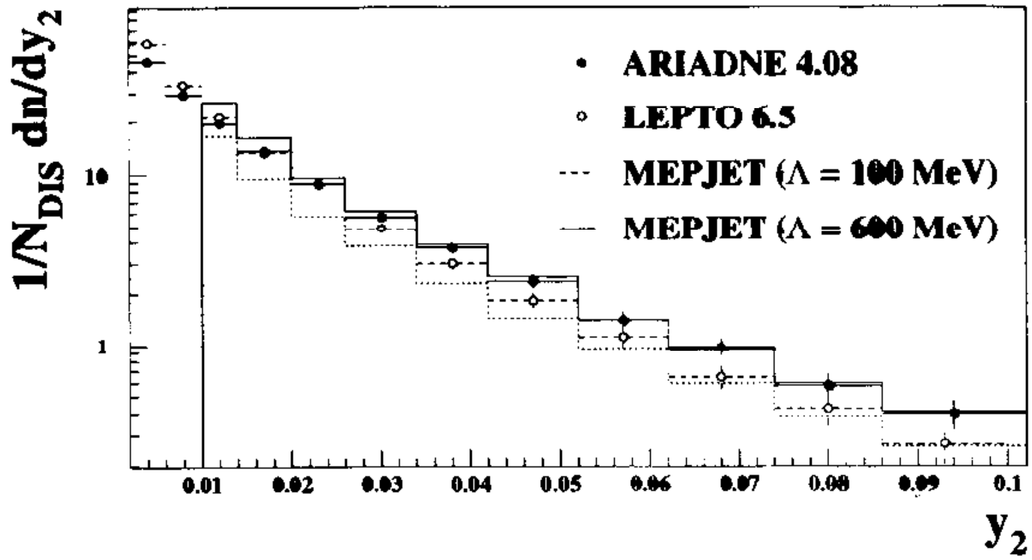
($Q^2 > 200$ GeV^2, $W^2 > 5000$ GeV^2, $y_2 > 0.01$, $\theta_{clus} > 7°$)

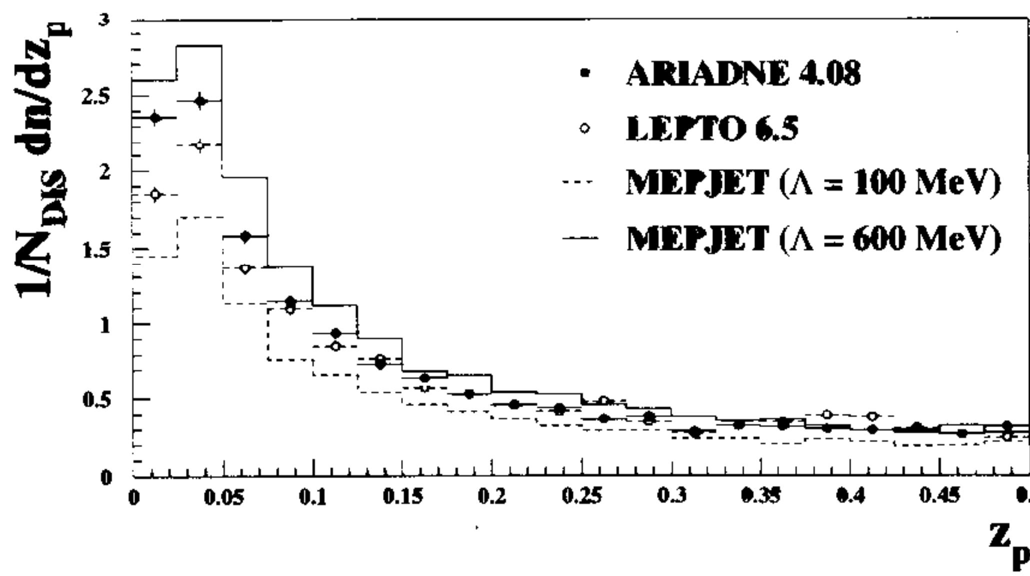


- a full set of complentary jet related observables was checked
- ARIADNE describes y_2 and z_p very well
- ARIADNE and LEPTO are poor in the description of the forward jet's polar angle distribution
- we unfold the data with ARIADNE in the following

NLO vs parton shower/dipole MC

(MSRH, $\mu_r^2 = \mu_f^2 = Q^2$, $y_2 > 0.01$)





- shape of NLO and ARIADNE/LEPTO y_2 distributions agree well

  agreement of 'normalization' is not expected for extreme values of $\Lambda^{(4)}_{\overline{MS}} = 100$ MeV and 600 MeV

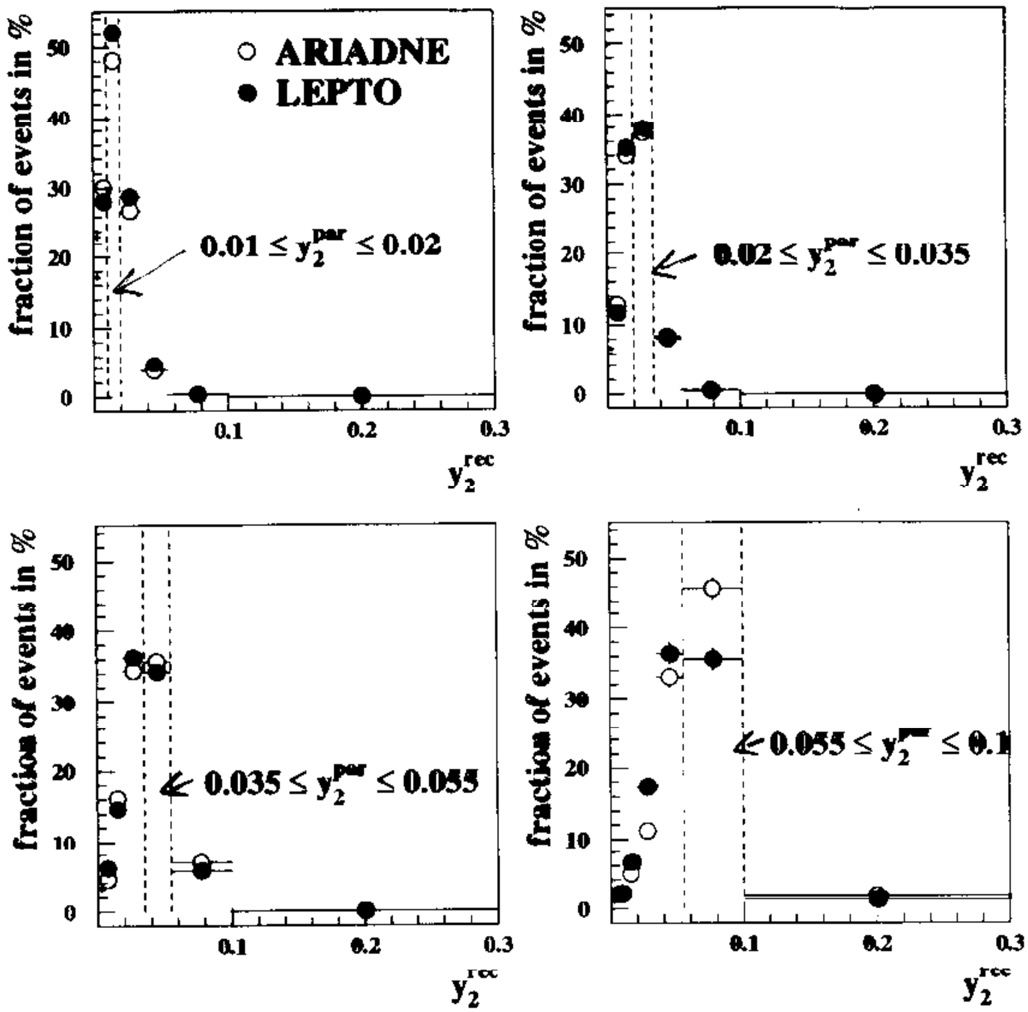
- shape of NLO and ARIADNE/LEPTO agree well in z_p; ARIADNE and LEPTO differ at small z_p

Unfolding method

(Blobel unfolding)

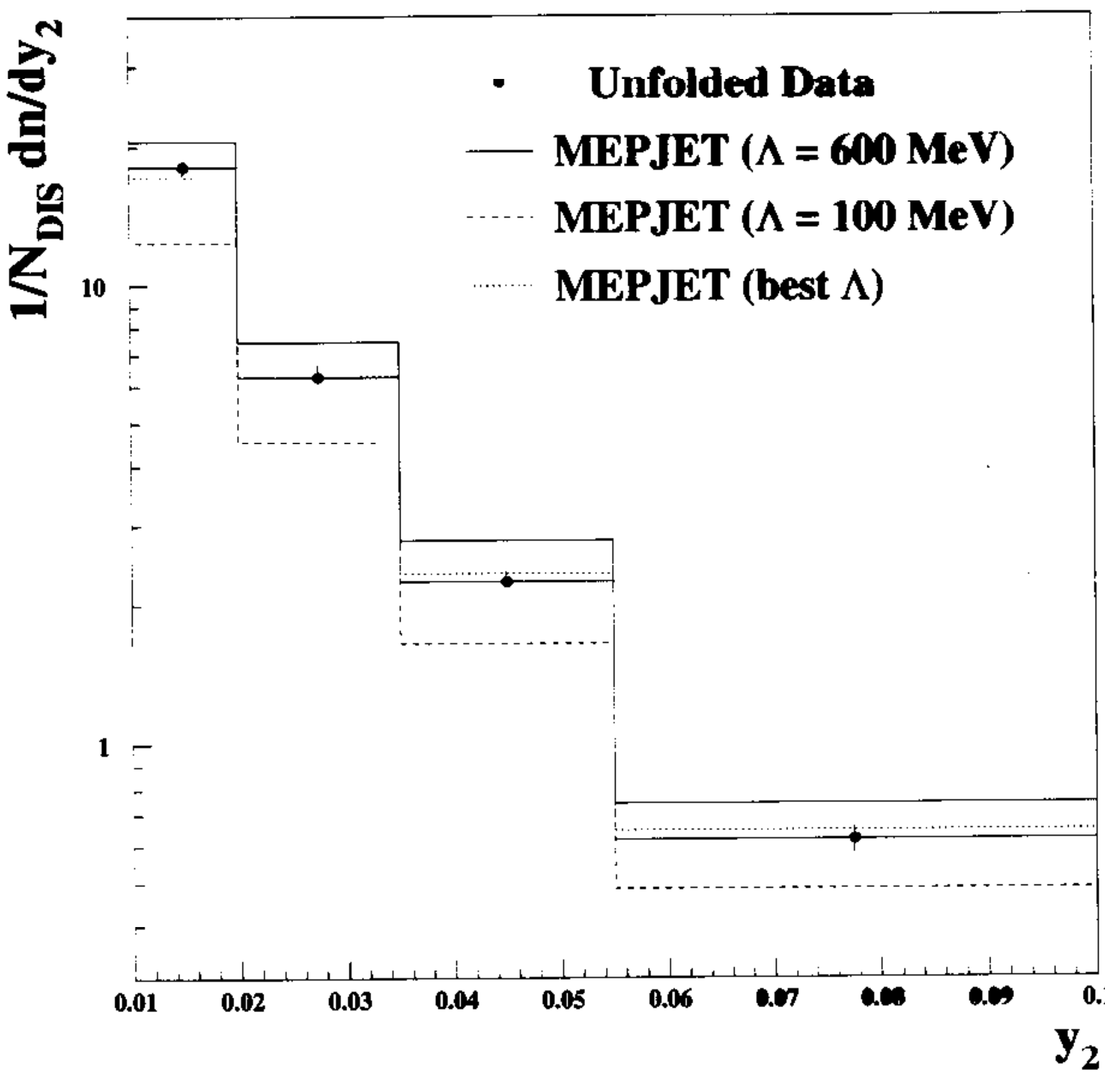
- one step unfolding of hadronization and detector effects
- y_2^{clus} and y_2^{par} are calculated for each MC event
- a cut of $\theta_{par} > 7°$ is applied calculating y_2^{par} to minimize model dependence when extrapolating into forward region
- y_2^{par} is reweighted such that y_2^{clus} fits y_2^{data}
  (weighting function is found by log-likelyhood method. oscillating solutions are suppressed)
- result consists of: 4 bins of unfolded y_2 distribution plus full information of statistical correlations

Hadronization and detector effects



- rather similar smearing effects are expected by ARIADNE and LEPTO
- size of migration excludes unfolding by correction factor method
- sophisticated unfolding method is applied which considers migrations and provides covariance matrix of statistical errors

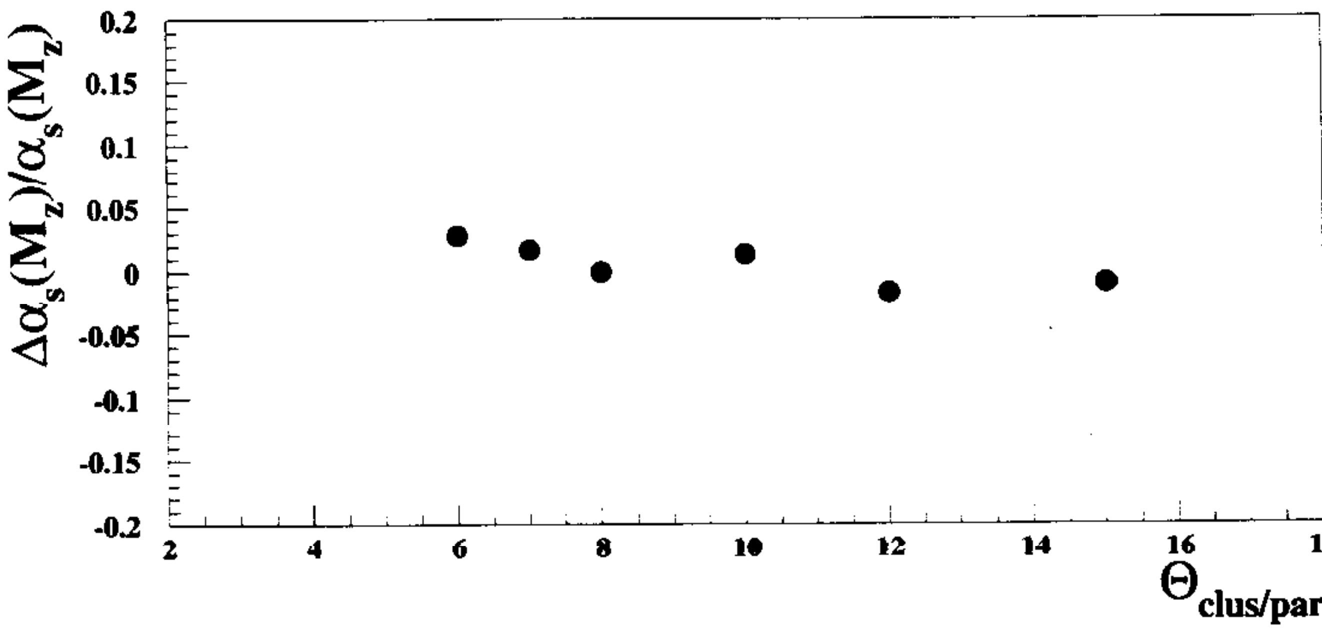
Sensitivity to α_s



- differential jet rate is clearly sensitive to value of α_s
- $\Lambda^{(4)}_{\overline{MS}}$ is fitted to unfolded data considering statistical correlation between bins
  (unfolding is based on ARIADNE)
- NLO and unfolded data agree excellently for α_s^{fit}

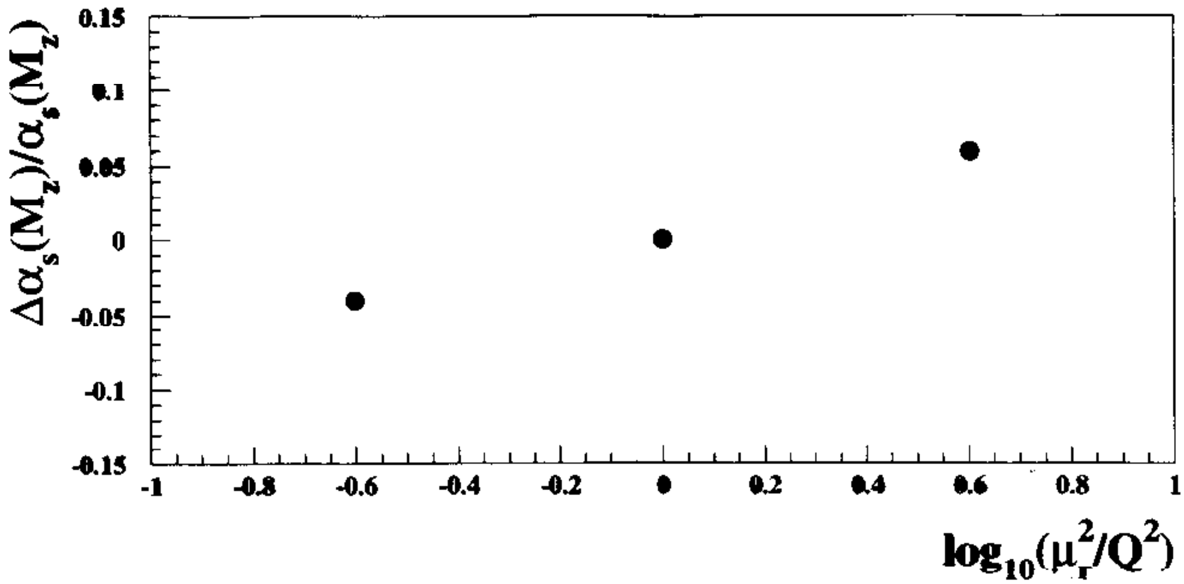
Study of systematic errors

(variation of θ_{clus} and θ_{par} cuts)



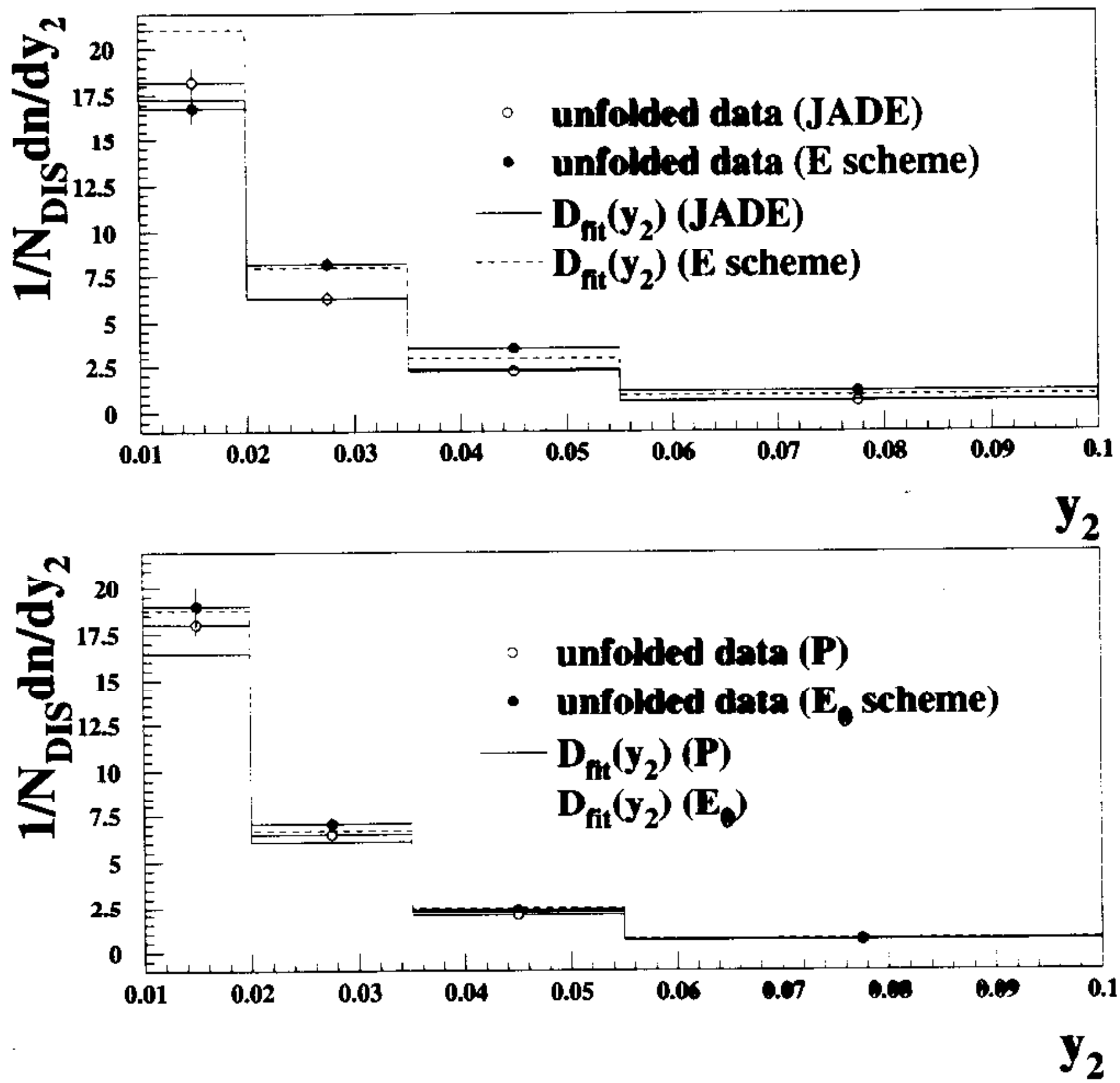
- main motivation for cut $\theta_{clus} > 7°$ is limited detector acceptance
- jet rate is unfolded for $\theta_{par} = \theta_{clus}$
  (to avoid model dependent extrapolation into forward region)
- identical θ_{par} cut is applied in NLO
- maximum change of $\alpha_s(M_Z)$ is +2% and −3%
- no significant $\theta_{clus}/\theta_{par}$ dependence of α_s is seen for $\theta_{clus} > 6°$

Renormalization scale dependence



- main choice of renormalization scale is $\mu_r^2 = Q^2$ (Note that $Q^2 > 200$ GeV^2)
- setting the scale to $\mu_r^2 = 1/4\,Q^2$ and $\mu_r^2 = 4\,Q^2$ changes $\alpha_s(M_Z)$ by -4% and $+6\%$
- setting μ_r^2 to sum of jet p_t in the Breit frame changes $\alpha_s(M_Z)$ by $+4\%$
- the renormalization scale ambiguity gives one of the largest individual errors

Different recombination schemes



- different algorithms are qualitatively similar
- largest differences are observed between E scheme and JADE. E_0. and P scheme algorithms
- E. E_0. and P algorithms give completely compatible but slightly larger values of α_s

Conclusions

Differential jet rates

- y_2 is a good variable to measure α_s
- consistent determination of α_s with some precision is possible
- prominent uncertainties are due to:

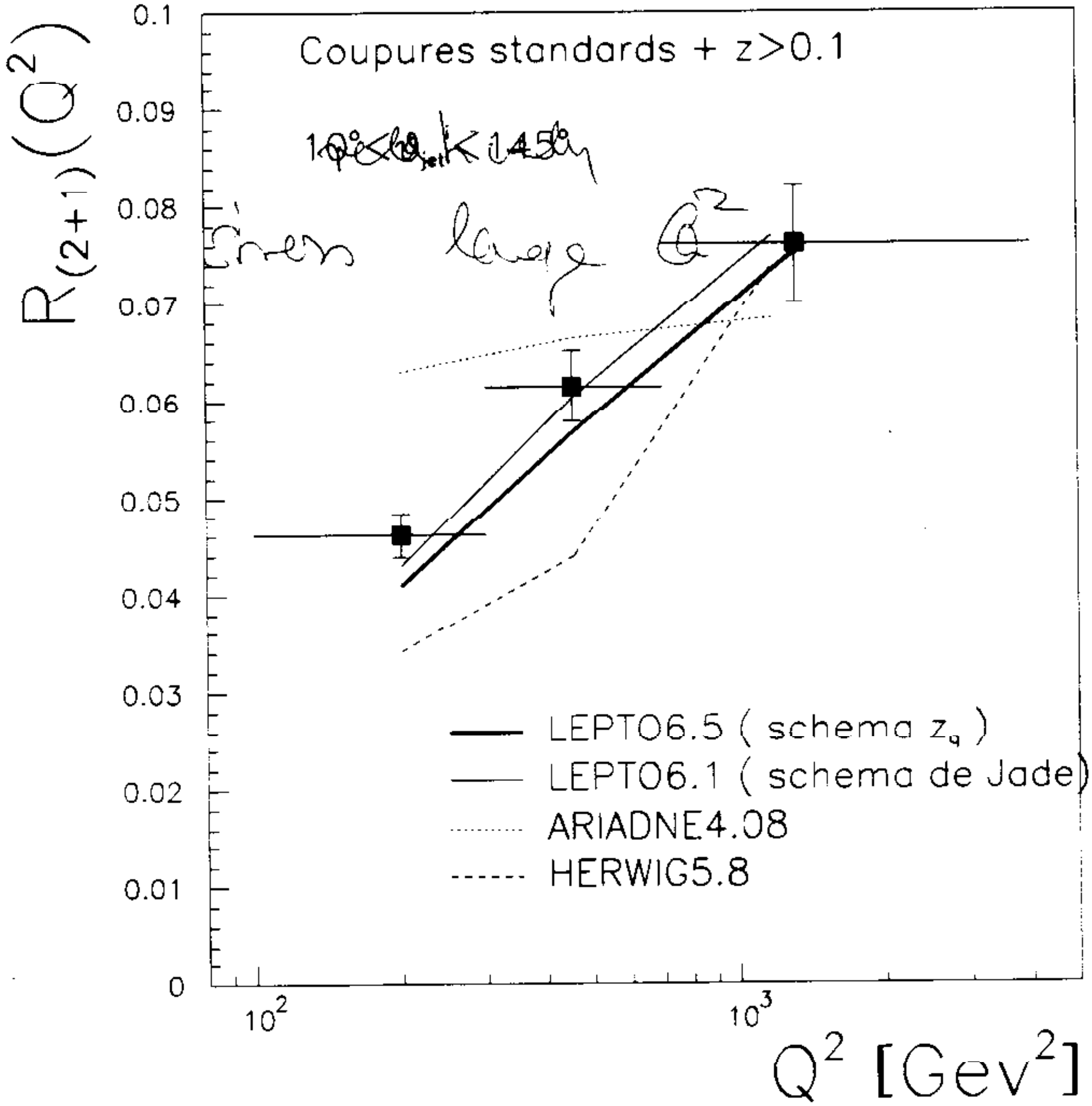
  description of data by QCD models
  what is the parton level?
  renormalization scale dependence
  choice of parton density functions
- working on correct estimate of model dependence with LEPTO 6.5

Outlook

- further reduction of model dependence is desirable
- higher statistics may allow to select more pronounced jets and to reduce hadronization effects
- test of QCD with alternative jet algorithms covering larger/different phase space region
- study of combined y_2 and Q^2 dependence

Integrated jet rate: Data vs Monte Carlo

JADE jet algorithm $y_{cut} = 0.02$



- LEPTO describes Q^2 dependence of R_{2+1} well: ARIADNE shows too flat Q^2 dependence
- LEPTO is the preferred model to correct the data
- control distribution like θ_{jet}, z_p etc. are discribed by LEPTO and ARIADNE however

Summary

- α_s can be determined from measurement of both integrated and differential jet rates at HERA
- large spectrum of systematic studies has started with the advent of the flexible NLO programs MEPJET and DISENT
- main difficulties/uncertainties of the analyses are:

  description of data by QCD models
  what is the parton level?
  renormalization scale dependence
  choice of parton density functions
- the best method to determine α_s from jet studies at HERA has yet to be found